PUBLIC LIBRARY ST. LOUIS

TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

CONTENTS

	Page
Some Applications of Light-Sensitive Cells By R. C. Walker - - - - - -	129
Some Applications of Photo-Electric Cells to Problems of Daylight Illumination By L. H. McDermott - - - - -	135
The Rectifier Photo-Electric Cell Applied to the Control of Gas-Lighting By W. H. B. Hall - - - - - -	139

VOLUME I—No. 9
SEPTEMBER, 1936

32 VICTORIA STREET
LONDON SW1

SOME APPLICATIONS OF LIGHT-SENSITIVE CELLS

by R. C. WALKER, B.Sc.(Lond.), A.M.I.E.E., A.M.I.Mech.E.
(Member)

(Paper read on Tuesday, April 7th, 1936).

The light sensitive devices in industry are confined to the three important types—the selenium cell, the alkali metal cell, and the rectifier cell. Many others exist, but they are of academic interest only and of little practical importance. Each of the types in question has its own sphere of utility, its advantages, and drawbacks.

TYPES OF LIGHT-SENSITIVE CELLS.

The Selenium Cell.

The selenium cell, which is the oldest and upon which most attention has in the past been bestowed, generally consists of a crystalline preparation of the element deposited between two spirals of wire forming the electrodes wound on a rectangular plate. The resistance between the two electrodes decreases as the illumination increases. The cell requires an applied potential, and in a typical case the current which passes may vary in a ratio of 1:10 for a change from darkness to full illumination. For measurement of illumination, the selenium cell is practically useless, by reason of the dependence of its behaviour on its previous history and the cycle of events through which it last passed. Its response to intermittent light of audio frequency falls considerably as the rate of interruption is increased. For this reason it has now no longer any prominent place in the field of sound reproduction or applications which involve the same general principles. But it is still extremely useful to simple trigger circuits where a change of illumination is required to open or close a relay and control some exterior circuit, particularly for small changes in illumination of low intensity. Frequently the current is amplified by a simple valve circuit, but attention may be called here to a useful method of actuating a relay which involves a circuit having no valve or replaceable component, and which is particularly useful for such applications as street lighting control or automatic switching of a lighting load upon the approach of nightfall or failing daylight and where a delay in operation of say half a minute is of little consequence.

The selenium cell S is in series with an adjustable resistance R across the supply mains. The centre point is connected to a condenser C in parallel with a neon lamp N and the polarised relay B/2, the circuit being continued through relay contracts b_1, as shown in the illustration. The lighting load is controlled by relay contacts b_2. The condenser circuit is of the type in common use in automatic traffic signal controllers.

Fig. 1 shows the condition when daylight is falling and the resistance across the cell S rising. Under these conditions the potential across points 1.2 eventually becomes high enough for the condenser to discharge through the neon lamp and impulse the relay B/2 bringing contacts b_1 to upper position and switching the lamp load on through b_2. This condition obtains until the illumination on S starts to increase and the potential across points 1.3 to rise. Eventually

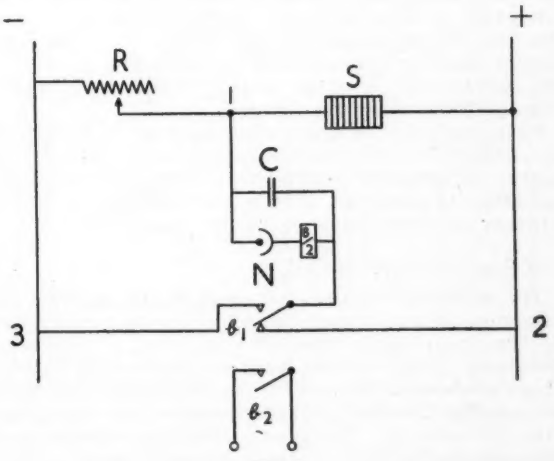

Fig. 1.

this is sufficient for a further pulse to pass through relay B/2 and restore the original condition with the lamp load out of circuit.

The Alkali Metal Photocell.

The alkali metal photocells are of the type in which luminous radiation produces an electron emission from the light-sensitive surface, the electron path being completed through the second electrode or anode and the source of applied potential.

With one or two notable exceptions, the cathodes are of composite form, usually of a thin layer of potassium or caesium on oxidised copper or silver. In all cases except where the mere detection of a change from light to darkness is the object in view, the vacuum cell is to be preferred to the gas-filled type. Under conditions of current saturation, the photoelectric current in the former type is directly proportional to the illumination, and for precision measurements this type of cell is superior to all others.

The gasfilled cell has the merit of increased sensitivity, and is therefore useful for simple trigger circuits involving a single stage of valve amplification, but high magnification of the primary current at

voltages approaching the glow discharge potential is secured at the expense of stability and accuracy of repetition.

Frequently an application may demand both high sensitivity and linearity of response, and the use of the gasfilled cell at low magnification is usually an attempt to secure a satisfactory compromise between these two characteristics which are to some extent mutually exclusive. Composite cathode cells, as distinct from the plain alkali cathodes, are not seriously affected by all reasonable temperature changes, but the small currents involved necessitate particular care in design to avoid insulation leakage. As in the case of the selenium cell, the caesium-silver oxide cell has some sensitivity to the shorter infra-red spectrum, so commercial apparatus can in some circumstances be operated by invisible rays. Projector lamps in conjunction with Ilford infra-red filters may be employed, but the arrangement is inefficient in view of the fact that the greater portion of the useful radiation is absorbed by the filter.

Plain cathodes of potassium, sodium, or cadmium, are useful for detection and measurement in the nearer ultra-violet spectrum, and in such cases the radiation is admitted to the cell through a quartz window suitably attached to the main bulb.

The Rectifier Type of Cell.

The selenium iron rectifier cell is the modern development of the copper oxide rectifier cell which had its inception in its use for providing a means of obtaining direct current from an alternating supply. There are several types of this cell which differ from one another in detail, but all have certain characteristics in common. The great advantage of this type is its simplicity, since it requires no applied potential, and can be used directly with a suitable meter to give current readings. Under these conditions, however, the current may not be proportional to the illumination and errors up to 20 per cent. may occur, except when the light is very small and the temperature constant, under which conditions approximate linearity may be obtained.

For some purposes, such as in the rough measuring of illumination, or in photographic exposure meters, such errors may not be vitally important, but if it is desired to reduce the error to 1 per cent. or 2 per

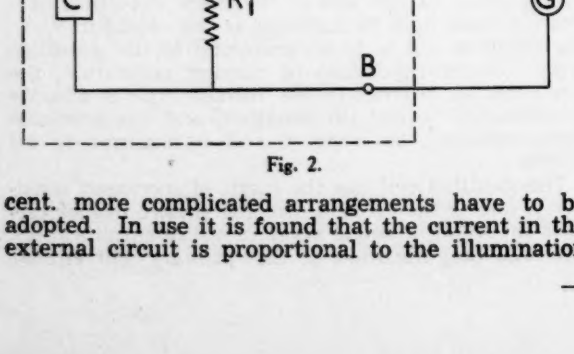

Fig. 2.

cent. more complicated arrangements have to be adopted. In use it is found that the current in the external circuit is proportional to the illumination only so long as the external resistance is small, say of the order of 50 ohms or less. The temperature error is generally of the order of 0.3 to 0.5 per cent. per degree C. Cells of this kind are electrically equivalent to the network shown in Fig. 2, where the terminals of the cell are at AB and the external circuit is to the right of these points, the equivalent internal series resistances being R_2 and R_3 with the shunt resistance R_1. As the illumination is increased, the shunt resistance R_1 decreases so that the current in the external circuit increases at a slower rate than the illumination. In practice, the convenience of the rectifier cell has led to its use with portable instruments which are necessarily of limited sensitivity, necessitating comparatively large illumination which accentuates the errors previously referred to. If indirect methods of measurement are permissible, a compensating circuit in which the potential across the cell is reduced to zero by an auxiliary potentiometer, and the photoelectric current estimated for each illumination in terms of the division of the resistance may be used (Pat. No. 422,725). With such a method, an accuracy of about 2 per cent. can be obtained for all intensities of light and reasonable variations of temperature.

The spectral response of the rectifier type of cell approximates more nearly to that of the eye than any of the emission cells. At high illuminations, some fatigue is noticeable and the output will fall slightly to a stable value during the initial period of exposure. Some error is introduced when the incidence of the radiation exceeds about 60°, i.e., the cells do not obey the cosine law.

In illumination meters calibrated for use with gasfilled lamps the readings are subject to correction if the meters are used in daylight or with discharge tubes, and the correction of the indicated recording may amount to 25 per cent. in extreme cases.

Rectifier cells are not suitable for use with valve amplification, since the internal resistance of the cell is small; neither is the use of a transformer coupling with interrupted light an efficient arrangement, since the power available is exceedingly small and the condition of low external resistance with high primary transformer impedance is difficult to fulfil.

APPLICATION OF CELLS.

In only a comparatively few instances is the measurement or detection of radiation the sole object in view. In general it is merely an intermediate or indirect process to gain information about a variable whose changes can be measured directly only with difficulty, but whose relation to absorption or transmission of specific wave-length is known, and such processes can be classified under the headings of measurement, detection, or comparison.

For industrial use, the direct operation of a relay by any light-sensitive device, which is practicable under laboratory conditions, is seldom satisfactory by reason of the inherently delicate nature of such a relay. Similarly, cases where the emissive type of cell is applicable to electrostatic methods of measurement, and where the photoelectric currents

are estimated in terms of the rate of charging a condenser, are of limited industrial use, though the substitution of the valve voltmeter for the electrometer as an indicator enables a reasonably robust form of detection to be employed.

Measurement usually demands a linear relation between the amplified and the photoelectric currents, and strictly the applications of television, phototelegraphy, and sound reproduction come under this heading. Fortunately, acoustic reproduction does not involve strict linearity, since the sense of hearing is sufficiently defective to be able to tolerate considerable distortion without perception.

Amplification.

If the amplification is very high, as in television transmission, the elaboration of the amplifier to secure an approximately linear output is very considerable. This is, of course, mainly a problem of amplifier design and need not concern us further here. This example is, however, indicative of the general principle that the use of a multi-stage amplifier employing commercial valves for the linear amplification of feeble photoelectric currents may involve too much elaboration for general industrial use.

Fortunately, much of the objection against commercial valves can be mitigated by selection and the use of balanced bridge circuits, and has now been further alleviated by the development of the electrometer triode, and the unit which combines this triode with a photocell in an evacuated envelope.

It is an adventage if a problem involving quantitative estimation can be converted into one in which the amplifier plays the part of a comparator in establishing an equilibrium position. This is exemplified in the type of comparator, in which comparisons are made between light reflected from two different surfaces. The reflected light from each surface in turn and in very rapid succession is directed by means of a rotating shutter on to the photocell. Any inequality in the two illuminations is amplified and the output current caused to actuate a shutter which gradually cuts off the brighter of the two beams until equality is attained, and there is no resultant photoelectric or amplified current. This condition of balance is at the same time recorded by means of a marker on a chart, and the comparison is then repeated for monochromatic light of some other wavelength till the whole spectrum, or any required portion of it, is covered. In this way a chart giving some correlation between the selective reflection between the two surfaces can be obtained. The principle of the method used is important, because its accuracy in no way depends on the amplifier characteristics, since only the condition of "no current" is detected and any inaccuracy due to drift in valve characteristics is automatically eliminated.

Trigger Circuits.

The great majority of industrial applications do not, fortunately, demand conditions which involve the difficulties of linear amplification previously mentioned. In most cases, mere detection is required and is very easily met by simple and efficient apparatus. The ultimate object usually is to close or open a controlled circuit when a specified change in illumination on the photocell takes place, the change being frequently from a maximum to zero or vice versa.

The photoelectric current can be made to change the potential of the grid circuit of a thermionic valve, and start or stop the anode current. The incidence of light on the cell may:

(a) reduce the negative bias of the grid to a less negative value; or

(b) change the grid potential from a positive or zero value to negative;

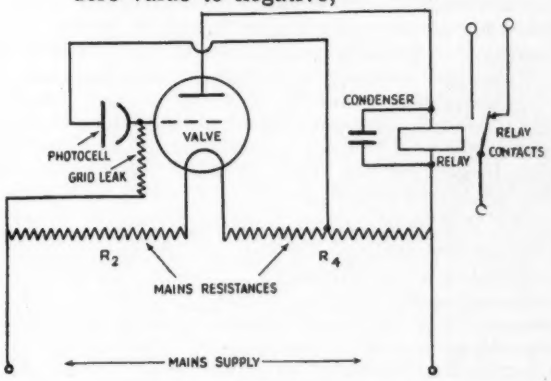

Fig. 3.

and the circuits to incorporate either of these operations are very easily adapted for operation from supply mains.

Fig. 3 shows a circuit involving operation (a), and Fig. 4 operation (b). In both of the cases shown, the valve filament is connected in series with

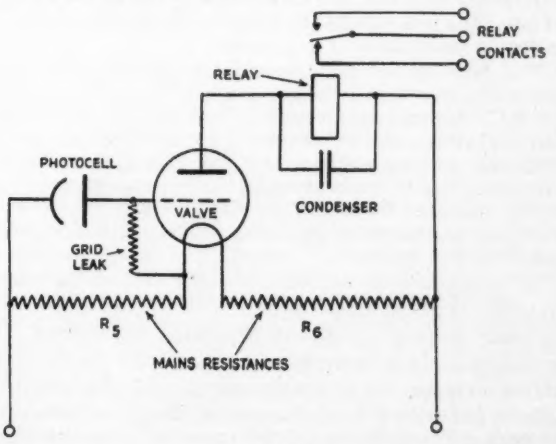

Fig. 4.

resistances across the mains, the resistances being subdivided to give appropriate values of p.d. to the anode of the valve and the photocell. In Fig. 3 the grid of the valve is biased negatively by the p.d. across R_2 and the anode current

is zero when the cell is dark. Incidence of light on the photocell reduces the bias and allows current to pass through the relay in the anode circuit. In Fig. 4 practically the reverse action takes place. In the second case, the grid and filament are at the same potential when the cell is dark, and current passes in the relay in the anode circuit. The incidence of light on the cathode of the photocell produces an emission which first neutralises the valve grid current and then establishes a negative potential on the grid, reducing the anode current to zero. Since the photoelectric current required to reduce the grid potential to zero is greater than that necessary to maintain it in this condition, there is a difference in intensity between the illuminations required to switch the relay from the "on" to the "off" position and vice versa—a condition which is favourable to the maintenance of stability of operation. The circuit has also, in general, the merit of higher sensitivity than that involving operation (a).

The grid leak, which is normally of the order of 10 megohms, restores the grid to its original potential.

If A.C. is substituted as a source of supply, the potential applied to the anode of the valve and the photocell cathode are of opposite phase, so that during one half of the cycle the conditions are the same as on D.C. Consequently, if the relay can be made to overhang the negative half-cycle during which the current through it will be zero by reason of the rectifying action of the valve, the operation of the circuit will be satisfactory on this type of supply. To secure this condition the telephone relay coil must be shunted by a large condenser, otherwise it will chatter badly.

If the relay is suitably adjusted, both these circuits can be made to operate satisfactorily for slow changes of illumination where the trigger action of the circuit is less pronounced.

The only merit of using resistances in the filament circuit is that the arrangement can be used for A.C. or D.C. indiscriminately, but heating of the resistances restricts the valve used to one of the minimum filament current rating, i.e., the L21 class. Either circuit is more economically and equally satisfactorily operated from A.C. through a transformer with suitable windings to give the voltage division indicated in the figure.

In cases where extremely rapid detection is required, recourse may be had to the grid controlled mercury vapour tube, the photocell controlling the grid circuit in a somewhat similar way to the case of the trigger valve arrangement. If the mercury tube is fed with D.C. in its anode circuit, a light flash or period of darkness of the order of a millisecond is sufficient to release the discharge and close the associated relay circuit. The mercury tube may be preceded by one or more stages of valve amplification for the highest sensitivity, the limit of which is set usually by parasitic disturbances which find their way into the circuit by paths other than photocell input circuit.

Acoustic Reproduction.

The principles involved in acoustic reproduction from sound films are now common knowledge, but many industrial applications of the sound film outside the field of entertainment are now well established, particularly those for repeating warning of the opening or closing of lift gates, announcing the record of automatic weighting machines, which are in daily operation.

A telephone service which is shortly to be inaugurated on automatic exchanges will enable the subscriber to hear the time of day repeated verbally to him by dialling the appropriate call sign on his receiver. In this case the hours and minutes are recorded on film, and the selection of the appropriate record is made by chronoscope mechanism so that the correct answer is transmitted to the subscriber.

Applications in Television.

Possibly the greatest demands are made on the photocell in television transmission, to which only brief references can be made here. The extremely high frequencies involved and the low intensity of illumination present in any directly televised scenes are but two of the difficulties which call for attention in the design of the light-sensitive device. The alkali metal vacuum cell alone is of much service in the transmitter. The frequency range involved precludes the use of the gasfilled cell, the selenium cell, or the rectifier cell, and the low illumination calls for cells of large cathode areas; cathodes up to 40 sq. ins. have been produced for high definition transmission.

The transmission of still pictures by wire or radio, as exemplified in newspaper transmissions of which almost every daily paper has its regular service, involves the same general principles, but the difficulties are far less by reason of the much lower frequency range involved. In some apparatus of this type the older form of potassium cathode with moderate gas magnification, in conjunction with low noise level valves, is still preferred to the more modern composite layer cathodes.

INDUSTRIAL APPLICATIONS.

The simplest industrial applications of photocells are frequently the most useful ones. A case in point is illustrated by the counting of objects passing along a conveyor or being delivered from a machine after a manufacturing process. If the objects are light in weight or awkward in shape and size, and particularly if their dimensions are variable, counting by mechanical means or by the use of an electrical contact may lack the positive action required for an accurate record. Here the photoelectric method has a great advantage. The electromagnetic counter is invariably the component which sets the limit of the rate at which the record can be made. High speeds can be made in multiple units; tens, or twenty-fives. In such cases the articles concerned are frequently of low individual value, e.g., cigarettes, and

the accuracy of counting may not be required to be greater than the smallest multiple recorded. Consequently, the amplifier relay can be arranged to close the charging circuit of a condenser at each impulse, the condenser discharging through a neon lamp and auxiliary relay which actuates the counter at each discharge. Since the operation of the counter depends essentially on the constancy of the number of impulses to raise the condenser potential to the discharge point the arrangement is not capable of great accuracy, but is frequently good enough to be preferable to the more elaborate and expensive arrangements.

Considerable interest has been taken in photoelectric control in the paper-making and associated industries. These include:

(a) Giving warning when the web fractures on high speed paper-making and printing machines.

(b) Controlling the process of re-reeling, particularly in the case of parchment paper.

(c) Securing correct register of double printing processes, or accuracy in impression in such processes as printing paper bags, etc.

(d) Counting newspapers, or printed matter, as delivered from the machine.

In the case of (a) the arrangement is extremely simple, since the cell and lamp are mounted on opposite sides of the web which normally obstructs the light. The fracture of the sheet allows light to reach the cell and close the alarm relay contacts. A number of high-speed paper-making machines with web speeds up to 1,000 feet per minute are now equipped with photoelectric controls of this type. Usually a multi-point control is installed and the valve circuits taken to a common switchboard where the condition of valve emission is always in view. A fracture of paper moving at such high speeds results in an accumulation of waste material which, if unnoticed, may take twenty minutes to clear. Mechanical contact with the paper is objectionable, as a trailing contact is liable to leave a mark on the surface. The possibility of using such a contact at the wet end of the process offers even greater difficulty.

In the operation of re-reeling, photoelectric control can secure proper alignment of the paper and correct any side lay which may take place during the process. Usually two photocells are employed, one on either side of the sheet. They can normally both be obscured or both just clear of the edge since movement of the paper sideways in either direction will result in the illumination of one and obscuring of the other. By interconnecting the relays of the amplifiers associated with the photocells the set of the receiving roller can be altered so that the tendency of the paper to move sideways is corrected automatically.

In case (c) an example may be quoted by way of illustration. In the making of paper bags the process of cutting is performed after the printed impression has been made on the paper. It is essential that the printed impression shall be centrally placed on the cut sheet. In practice, if uncontrolled, the paper tends to creep in one direction or the other during the cutting process, so that the printed impression becomes eccentric on the bag. To obviate this error an opaque spot or a perforation—usually the former—is made on the side of the sheet during the process of printing and at a point which is fixed relative to the design. Normally the cutting mechanism is synchronised with the position of the opaque spot covering the photocell. The paper may be set to run slightly too fast so that the interruption tends to occur too early in the cycle when a braking control is brought into operation in the driving motor circuit to restore synchronism. In another arrangement a rotating commutator controlling the grid circuits of two mercury discharge tubes, which in turn control the field circuits of variable speed motor actuating the coupling mechanism, is synchronised mechanically with the correct position of the opaque spot in such a way that acceleration or retardation of the paper speed can be secured according as the light interruption is early or late in the cycle.

Protective circuits in the form of burglar alarms are frequently designed to include photoelectric equipment in conjunction with the ordinary spring contacts, the relay contacts in the amplifier forming part of the closed circuit system. Unnecessary objection is sometimes raised to the existence of the valve in the amplifier since this is essentially a vulnerable component. Failure to operate by reason of damage to the valve can be obviated either by the use of a four-electrode valve with an alarm relay in the auxiliary grid circuit, in which the current is maintained and is independent of the existence of current in the anode circuit so long as the valve is intact, but closes circuit as soon as the filament emission is cut off; or the circuit may be arranged so that the relay contacts move to the alarm position when the valve or any component is accidentally or maliciously damaged.

A useful industrial application is that of smoke detection in factory chimneys. The simplest arrangement of spanning the base of the flue with a pencil of light is frequently the most satisfactory. Restriction of the aperture through which the light passes to reach the cell can be made so that the slightest cut-off will close the relay circuit. In this way smoke may be indicated at any predetermined and agreed density. A complete record of the times when excessive smoke has passed can be made by means of a chart recorder. It is often considered—and with justification—that a qualitative record which merely shows "smoke" or "no smoke" is preferable to the quantitative record which indicates degrees of smoke density. Not only is it difficult to establish a calibration for all thicknesses of smoke strata, but any such device which is operated by the valve anode current depends for its accuracy on the constancy of that current which cannot be guaranteed throughout the whole of its useful life.

The control of advertising signs by daylight and darkness is now well established, but little attention seems to have been given to other methods of operating signs which may be economical and of advertising value. For instance, many large signs are now installed beside main line railways where they are

distinctly uneconomical. If the simple expedient of switching on by the passage of a train through a light beam were adopted there would be the advantage of saving in power and the sudden switching on of the sign would enhance its advertising value. Similarly the control of signs by motor-car headlights is another economical proposition which, though installed in a few places, is capable of more extensive use.

The London Electric Railways have made considerable use of light sensitive devices, notably in connection with the control of warning lights on curved platforms where a gap exists between the edge of the platform and the step of the car. In this case the source of illumination and amplifier are mounted side by side, and a reflecting surface installed at the opposite side of the tunnel at the train exit end of the platform, so that the beam of light is cut off when the driver's cab comes to rest.

At stations where there are periods of light passenger traffic at certain hours of the day it is an advantage to operate the escalators at slow speeds where there are no passengers on them. Wear and tear on the mechanical gear is considerably reduced when such provision is made. The entrance of a passenger across the light beam to the footway closes the relay which controls the driving motor field, and the escalator speeds up smoothly. The same operation brings into circuit a time delay which enables the higher speed to continue for a specified period. This time period is restarted at each interruption of the light, so that the escalator does not revert to slow speed until the last passenger has left it. In both these examples direct operation by an electrical contact would be difficult and objectionable.

The timing of sporting events is another application which secures consistency of record. The passage of competitors through the light beam both at the start and finish of the race secures an accuracy which is far superior to that obtainable by hand timing, and the ultimate error due to relay lags, etc., can be made less than the accuracy to which the record is required.

Attempts have been made to measure and control furnace temperatures by the change in the quality of the radiated energy, but difficulty is experienced in the slow drift which occurs in the photocell and amplifier circuits, and great elaboration is necessary for consistent operation. A more satisfactory arrangement is that in which the temperature measurement is made by a thermocouple and is indicated by the usual lamp and scale. The photocell in the trigger type amplifier previously described can be set to bring the control into operation when the galvanometer spot reaches a predetermined point on the scale or to maintain it between two fixed points.

Space has permitted but a brief reference to a few of the useful applications of photocells.

Problems to which it is intended to apply them are often not photoelectric problems at all, but optical, electrical, or mechanical, and the mechanical difficulties frequently outweigh all others, and usually are the deciding factors as to whether a scheme is practicable or not.

With a few exceptions, alternatives to the photoelectric method of control can be devised, and the examples cited are merely indicative of cases where the photoelectric control has definite advantages.

SOME APPLICATIONS OF PHOTO-ELECTRIC CELLS TO PROBLEMS OF DAYLIGHT ILLUMINATION

by L. H. McDERMOTT, B.Sc., A.R.C.S., A.Inst.P.
(National Physical Laboratory).
(Member).

(Paper read on Tuesday, April 7th, 1936.)

ABSTRACT:

The following paper describes three distinct ways in which photo-electric cells have been used in connection with problems of daylight illumination. The first deals with a photo-electric relay control for the lighting of part of the National Portrait Gallery, the second with the continuous recording of daylight illumination at Teddington, and the third with an attempt to find out what is the lowest natural illumination which a worker will tolerate on the working plane

Of the three sections into which this paper is divided, the first is the only one which can be said to come directly within the scope of the title of this evening's papers in its more restricted sense; the other two can, however, be included in the subject in its wider aspect in that the photo-cell, even if not controlling the whole apparatus, certainly exercises a control over a portion of it.

Photo-Electric Relay Control.

The first part is concerned with a photo-electric apparatus which was installed at the National Portrait Gallery some years ago to control the artificial lighting over one of the large paintings exhibited there(1). For the details of this apparatus the author is much indebted to his colleague, Mr. J. S. Preston, who was responsible, not only for the design of the apparatus, but also for its assembly and installation.

The circuit employed was the well-known valve-bridge, with modifications to suit the special conditions for which it was used. The values were pentodes and were fed from the direct current mains by means of a potentiometer carrying approximately 1 amp. Across the two anodes was connected a Post Office relay, of the polarised type, and this in turn was connected to a mercury relay and switch controlling the lighting load of 5 amps. at 240 volts. A resistance of 15 megohms was used as the grid leak, and a condenser of 5 mfd. capacity was connected directly across the cell. This was of the bulk potassium gas-filled type, and was situated in a suitable housing in the window of the gallery nearest the picture. It was so placed that when the general illumination on the picture had fallen sufficiently low to necessitate use of the artificial lighting, the photo-current had fallen to the correct value to cause the operation of the first relay.

The condenser connected across the cell was introduced to nullify the effect of a temporary fall in the illumination, which would cause the lights to be switched on and off in fairly rapid succession. A sudden fall in the illumination tended to increase the internal resistance of the cell and thus to increase the voltage on the condenser. The charging current which brought about this increase flowed through the grid leak and, as far as the valve-bridge was concerned, produced the same effect as a photo-current. As long as this charging current continued to flow, the first relay remained open. If the illumination did not rise again within about ten minutes, the charging current had, at the end of this time, ceased flowing, and the relay contacts closed. If, however, the illumination at some time in this period rose again, the internal resistance of the cell showed a fall and the condenser began to discharge partly through the cell and partly through the grid leak. The discharge current through the latter was small in comparison with the now increased photo-current, and thus the net current did not decrease sufficiently to cause the relay to close. If the rise in illumination was large, the flow of current was often sufficient to cause a glow discharge in the cell; this did not, in practice, however, impair the cell's performance.

This arrangement of the apparatus was found to work quite satisfactorily over a considerable period, and was superseded by another apparatus only when the mains supply was changed from direct to alternating current.

Continuous Recording of Daylight Illumination.

An investigation which the author has been carrying out at the National Physical Laboratory during the last six years concerns the amount of daylight illumination which the constantly varying weather conditions permit of our receiving. It has long been realised that the amount of daylight received in any particular locality will have a considerable effect on the design and position of buildings, and, consequently, a knowledge of this amount and the manner in which the total is made up of contributions from various portions of the sky is of undoubted assistance to architects and others engaged on building construction.

It can readily be understood that when dealing with a phenomenon of such a fortuitously variable character as daylight illumination, it will be necessary to obtain records covering a considerable period before any really exact deductions can be drawn. Of the six years, during which these daylight measurements have been obtained almost continuously, the first three were devoted to

(1) "Illuminating Engineer," December, 1930.

measurements in the north octant only, and a paper descriptive of this work was published in 1932 ([2]).

Subsequent to this, measurements were extended to include the other three octants, and the adjustable screening device used is illustrated in Fig. 1. It is situated on the roof of the High Voltage Building

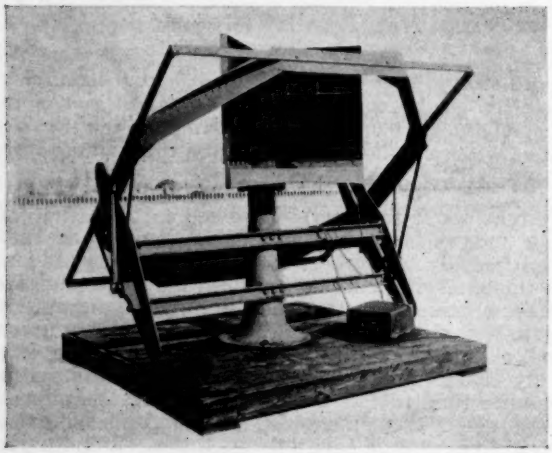

Fig. 1.

at the National Physical Laboratory, and, being 60 feet above ground, it commands a practically uninterrupted view of the whole sky. The two upright screens, which can be rotated, limit the light falling on the cell to that from any particular quadrant of the sky; since, however, light reaches the cell only from the upper half of any quadrant, the portion of the sky under consideration is thus referred to as an "octant." When mention is made of the "north octant," the region of the sky referred to is that included between the compass points north-west and north-east.

The cell, of the potassium hydride neon-filled type and covered with a wratten K3 filter, is mounted in the small box shown in the photograph in such a position that the axis of rotation of the screen passes through the sensitive surface. Immediately above the cell is placed a ground-glass window about 2 ins. square, the remainder of the top of the box being covered with opaque material. In order to render the cell-box water-tight, it is covered with a sheet of glass and is sealed with a special wax consisting of beeswax and resin. The leads from the cell are of heavy ignition cable, and the holes where they emerge from the cell-box are again heavily sealed. One of these leads is connected directly to the recording apparatus, while the other is connected first to the energising battery, contained in a metal box shown in the photograph. Serious leakage currents between the two leads to the recording apparatus are eliminated only when they are at nearly the same potential, and this is effected by placing the battery as near as possible to the cell. The octant and the battery box are both connected to the negative end of the battery.

As all measurements are concerned with skylight and not sunlight, the outside screen has been devised to cut off all direct sunlight from the cell. This screen, which is octagonal in shape, is strengthened by an outside framework of steel, and is sufficiently large to allow the vertical screens to rotate without fouling. The whole is supported at the sides by two steel blocks, which can be clamped at any position in two parallel slots, inclined at an angle of 51½ deg. to the vertical. These blocks are thus adjustable in position according to the varying altitude of the sun at different times of the year. In practice this arrangement has been found to work very satisfactorily for varying positions of the screen and for all hours of the day.

In a small room near the top of the building, the recorder itself is housed. This housing consists of a large wooden box separated into two compartments, there being a slit about 1-8 in. wide extending almost across the partition. In one part of the box is a sensitive moving coil galvanometer, to which are connected the two leads from the cell, the negative lead here being earthed. The reflected spot from an illuminated aperture falls on the slit and is received on a photographic sheet, which is slowly rotated by a system of rollers in the second part of the box.

The photographic sheets used are 10 ft. by 15 ins. in size, and are passed in front of the slit by a system of rollers at such a speed that the record is completely unwound in roughly seven days. A motor, mounted on a separate support, provides the motive power, and drives the rollers through a system of worms and pinions.

A series of marks are made along the edge of each record by means of a flash-lamp bulb illuminating a small aperture at the end of the long slit. These exposures are made at hourly intervals by the passing of the minute hand of a clock through a mercury cup.

By means of a time-switch, the whole of the recording apparatus, i.e., galvanometer lamp, timing lamp, and motor are switched off a short while after sunset and on again a short while before sunrise.

Records each covering one week are obtained from the four octants, north, west, south, and east in turn.

It has been found that in winter the photo-currents are never large enough to cause the spot to move beyond the end of the slit. Accordingly, for this time of the year, the galvanometer is used unshunted, but for other times when the current dealt with is much larger, a number of series and shunt resistances are used to vary the sensitivity of the galvanometer by regular steps to about one-twentieth of its normal value.

Calibration of these records is effected by visual measurements of daylight illumination carried out with a similar octant at stated times. In practice, it has been found that the sensitivity of the cell remains so constant that a knowledge of the reduction ratio of the shunt is almost sufficient for calibration. The records are all ruled up as shown in the illustrations and various measurements are carried out on them. For instance, the total area under each curve is determined, and this, when related to the area of a

([2]) "Illuminating Engineer," February, 1932.

rectangle representing a definite number of foot-candle-hours, gives the total daylight illumination received in each day. When dealing with the north octant only, the average of all such values for each month was obtained, and a curve showing the variation of average daily illumination with time of year was drawn. When the measurements were extended to the other octants the period became shortened to one week and the number of curves obtainable was increased to four. This naturally implies a four-fold increase in the total period of measurements in order to obtain the same representative results.

Another series of values has been obtained from the records by determining the average illumination for each hourly period; then by taking the means of corresponding values over a period of first a month and later a week, a number of curves showing the mean daily variation of illumination over the period selected has been built up.

Three types of records which have been obtained are illustrated in Figures 2, 3, and 4. Figure 2 gives

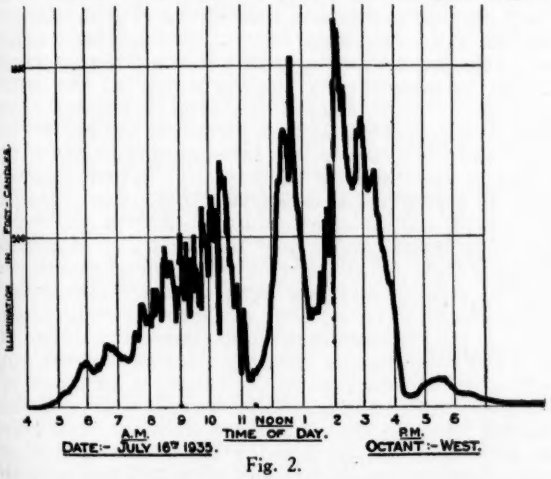

Fig. 2.

an idea of the variation in daylight illumination which can often be encountered on a summer day. Up till 10.30 a.m. the weather was fine, with blue sky and detached clouds; it then became overcast and the subsequent rapid changes are found to be the rule rather than the exception with this type of weather. A type of curve very rarely met with is given in Figure 3. It represents the illumination received during a cloudless day, and even this has several small blemishes. Figure 4, which was obtained on the following day gives an idea of the changes brought about by small light and dark clouds in an otherwise cloudless sky.

Determination of Minimum Working Illumination.

Another investigation, which is being carried out from the National Physical Laboratory, concerns the lowest value of natural illumination which an office worker with access to a source of artificial illumination will tolerate on the working plane. The object of the work is thus to determine the value

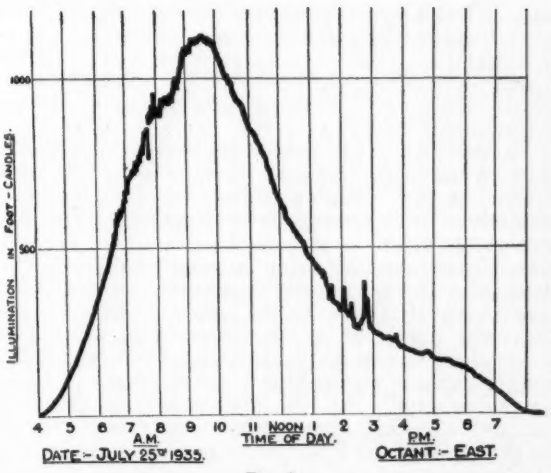

Fig. 3.

of daylight illumination at the instant when its insufficiency becomes so noticeable to the worker that the artificial light is switched on. In order that the results obtained may be of value, it was considered necessary that each subject should be almost continuously employed at the same desk, and that he or she should have control of a separate desk light which could be switched on independently of any other light in the office.

A preliminary investigation was carried out at the National Physical Laboratory itself early in 1935, and, in the building where the tests were conducted, there were only four subjects who could be said to fulfil

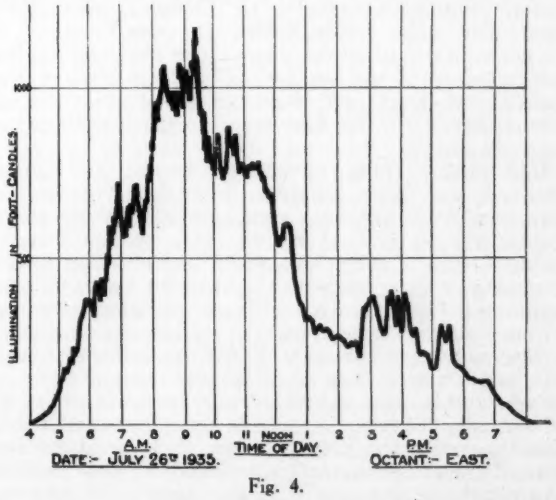

Fig. 4.

both the foregoing conditions; of these, three were typists and one a tracer. A demonstration of the apparatus employed was one of the items at the opening meeting of the Society.[3]

It was found that the results from only four subjects were somewhat inconclusive, but were, how-

[3] "Illuminating Engineer," December, 1935

ever, sufficiently encouraging to warrant an extension of the investigation to include a larger number of subjects. Those finally selected were eighteen typists in one of the typing pools in the Office of Works, Whitehall. Each of these subjects is almost continuously employed at the same desk, and each has a separate desk light independent of all other lights in the room. Also, as the positions of the desks relative to the windows differ considerably among themselves, it is anticipated that results covering a wide range are to be expected.

The experimental method employed is almost identical with that already described, the only difference being that the relay system, which, in the apparatus exhibited at the opening meeting, was designed for use on six subjects, has been replaced by another capable of working with eighteen. Further, the mains supply for the preliminary work at the National Physical Laboratory was direct current, while at the Office of Works the supply is alternating, this change necessitating a fresh design for the relay system.

Briefly, the method employed consists in photographing a microammeter, connected to a photocell, the motive force for working the camera being derived from the current in the lamp circuit when the subject first switches on the desk light. The photocell is exposed to daylight in a fixed position in one of the office windows, but by a calibration of the readings of the microammeter so obtained in terms of the illumination falling on any particular desk, it is possible, by a subsequent inspection of the microammeter reading on the photograph, to infer the value of the daylight illumination on that desk at the instant when the worker made use of the desk light.

The photo-electric-cell is of the selenium rectifier type, and after being tested for non-linearity of response to illumination, was placed close up against one window of the typing pool. This window was then screwed up, as it was found that even a small movement of the window-frame caused a change in the cell output.

The photographing is effected by using a 9.5mm. cine camera, with an f/1.9 lens with micrometer adjustment for focusing, and capable of taking single exposures. It is held rigidly in a special wooden holder, from which it can easily be removed for recharging. This, together with the rest of the apparatus, is placed on a small table situated as inconspicuously as possible in an ante-room.

The microammeter has a full-scale deflection of 240 micro-amps., but as it is kept permanently in circuit and is often subjected to currents of the order of 2 or 3 milliamps., a special spring stop is fitted. This prevents the pointer from sticking at the far side of the scale, which long periods in this position would otherwise cause it to do. It is viewed by the camera by means of a mirror inclined at an angle of 45°; from this mirror a portion of the silvering has been removed, so as to enable a small watch suspended behind the mirror also to be viewed by the camera.

In order to provide the motive power with which to work the camera, each desk lamp circuit was tapped in such a way that the two leads provided were live only when the desk lamp was switched on. Each pair of leads is connected to a Westinghouse rectifier and two 4 m.f.d. condensers connected in the correct manner for obtaining full-wave rectification, and to the resulting direct current output is connected in series a 2 m.f.d. condenser and a telephone relay of standard pattern, fitted with two independent pairs of contacts which "make" their respective circuits when the relay is operated.

The first pairs of contacts on all the relays are connected in parallel, and the circuit through each is completed by the actuating coil for the camera, and a connection to the secondary of a transformer. This actuating coil consists of about 1,500 turns of 26 S.W.G. enamelled copper wire, wound on a porcelain bobbin, which is placed over a soft iron rod; above this, a short steel bar, pivoted at one end, is suspended from the starting trigger of the camera. The transformer is provided with 5-volt tappings up to 60 volts, and it was found that the full voltage was required to work the camera trigger.

When any one of the desk lamps is switched on, a direct current is made to flow in the circuit containing the corresponding relay and condenser, until the latter has become charged to a sufficiently high voltage to prevent any further flow. In the small space of time in which this charging process takes place, the current flowing is sufficient to operate the relay, and the contacts are closed long enough for the actuating coil to work the camera. When a second lamp is switched on, a similar effect takes place in the corresponding relay and the camera shutter is again operated. As there is no electrical connection between the coil of the relay and the contacts, the switching on of any one lamp operates the camera irrespective of the number of lamps already alight. Then, as long as each desk lamp remains switched on, the 2 m.f.d. condenser remains charged and the contacts open. When a given desk lamp is switched off, however, the corresponding condensers are discharged through the desk lamp, rectifier, and relay winding, the current through the latter being now insufficient to operate it, and in a few seconds the circuit has regained its normal condition, without, in this case, making an exposure on the film.

By these means, an exposure is made only when an office light is switched on and the camera and actuating gear are automatically reset in readiness for the next occasion when a lamp is switched on.

To secure a record on the photograph to indicate to which desk each exposure applies, an indicator system has been devised. For this, the second pair of contacts on each relay is utilised. First, one contact of each pair is connected to one terminal of a screw holder for a 4.5 volt torch bulb; then the other terminals of the eighteen holders are connected together and the circuit is completed by a connection to a 5-volt tapping on the transformer and, finally, to a suitable resistance and a wire joining the remaining eighteen contacts. The eighteen bulb sockets are grouped as closely as possible in two rows of nine each, the bulbs being horizontal and facing the camera. They are placed in such a position that they are at the correct distance from the camera and appear in each photograph just below

the mirror. A blackened screen, pierced by eighteen small holes, is placed in position to reduce reflection from the bulbs themselves.

When a desk light is switched on, both pairs of contacts are closed for approximately the same time, and while the closing of one pair causes the camera trigger to be attracted downwards, the closing of the second pair causes the corresponding torch bulb to flash. A preliminary trial showed that in each case the flash appears on the film.

In the typing pool under consideration there are three main office lights, each of which makes a definite contribution to the light falling on each desk. It is thus of importance to know whether or not these lights are on when computing the total illumination in each instance. Accordingly, provision has been made for indicating when these lamps are switched on by having a 10-watt lamp connected in parallel with each, and these are mounted in a small box, from which the watch is suspended. A translucent numbered screen is placed in front of each small lamp. The date is also included to complete the necessary information.

The lighting for the micro-ammeter, etc., is provided by three 100-watt lamps, which are mounted in shell shades a few inches in front of the camera and an equal distance above the line in view.

The necessary calibration of each desk is effected by making simultaneous readings of the micro-ammeter and of the daylight illumination on each working plane. It may be a matter of opinion as to the exact location of the working plane in the case of a typist, but that chosen is on the desk at the side of the typewriter, where the material to be copied is found to be placed.

Measurements are also made of the artificial illumination received on each desk from the main office lights. Also, periodical calibration of the micro-ammeter reading with respect to the daylight illumination at some definite fixed point is carried out so as to allow for any change in the sensitivity of the cell, etc.

The author wishes to place on record his indebtedness to Mr. A. D. Fitzgibbon and Mr. Diprose, of the Office of Works, for valuable assistance rendered both in the installation of the apparatus and also the daily attention which they have given it, and to Mr. J. S. Preston and Mr. A. Felton for advice and help in the design of the apparatus.

THE RECTIFIER PHOTO-ELECTRIC CELL APPLIED TO THE CONTROL OF GAS-LIGHTING

By W. H. B. HALL, B.Sc.

(Paper read on Tuesday April 7th, 1936).

The South Metropolitan Gas Company was recently engaged in redesigning the gas lighting of a London school classroom. Whilst the work was in progress, a desire was expressed by the school authorities for an automatic device to light and extinguish the lamps when daylight illumination either falls below or exceeds a predetermined standard. The cost of the apparatus was to be moderate, and the mechanism should work for a school term with no other maintenance than that which could reasonably be asked of the teacher. To supply this demand the company has produced an automatic controller which works satisfactorily and fulfils the prescribed conditions.*

The controller is shown assembled in Fig. 1. It is built up from components which are in common use, comprising a rectifier photoelectric cell, a sensitive galvanometer relay fitted with a maximum and a minimum contact, a 3-volt dry cell, and a time-actuated street lamp controller of the same type as that already familiar to the Gas Industry. The complete unit, with the exception of the photoelectric cell, is included in an iron box 11 in. by 11 in. by 4 in., and, in use, is fitted in parallel with the main control tap of the lighting installation. The photo-electric cell can be placed in any suitable position in the room, and is connected to the rest of the apparatus by means of copper leads. The only component that has been modified is the street lamp controller. This has been altered by the removal of the time-actuating mechanism and its replacement by an electro-magnetic device for starting the spring motor, which turns the gas cock.

By the use of one relay in combination with a system of contacts to be described later, it is possible to supply all the energy for operating the electro-magnetic actuating device from a small 3-volt dry cell, which gives many months of service. The attention required from the teacher is, therefore, reduced to winding the spring of the motor, the frequency of which operation depends upon the number of times the gas cock is operated. The spring used actually requires rewinding after 150 operations of the gas cock.

The components of the device and the electrical connections are shown diagrammatically in Fig. 2. The photoelectric cell (1) is of the rectifier type. When light falls on its sensitised surface an electric current is generated, the magnitude of which depends primarily on the intensity of the light. The relay (2) (Fig. 2) is essentially a moving-coil galvanometer

* Provisionally protected.

arranged in such a manner that when the moving coil is deflected it carries with it a conductor A, which makes contact with B when the current flowing in the coil is a minimum, and with C when the current is a maximum. The component (3) (Fig. 2) is a small electro-magnet which, when energised, attracts a simple iron armature, to which is attached the starting lever of the spring motor. E and D represent two contacts, which are "made" and "broken" by the gas cock as it turns from the "off" to the "on" position. When the conductors of E are touching those of D are separated. These contacts are actually arranged so that when the relay conductors A and B are in contact D is separated. When A touches C the conductors at E are separated. The current from the battery, therefore, flows in one of the alternative paths, A, B, D, F or A, C, E, F.

The arrangement of the electro-magnet is illustrated in Fig. 3. When the magnet H is energised

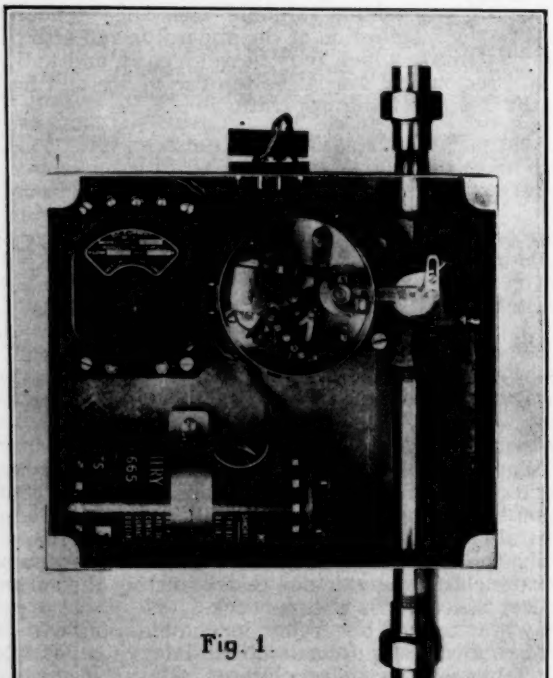

Fig. 1.

it attracts the armature I and operates the starting lever J of the spring motor by means of the link connecting I and J.

Attached to the shaft of the pinion turning the cock is a disc K which carries two lugs L and L^1. The two contacts E and D shown in Fig. 2 are represented in Fig. 3 by the contacts E, D, and O. O represents the common member which is joined directly to the electro-magnet (see Fig. 2). The second conductors of D and E (Fig. 2) are shown in Fig. 3 mounted respective above and below the common member O. The contacts are mounted in such a manner that

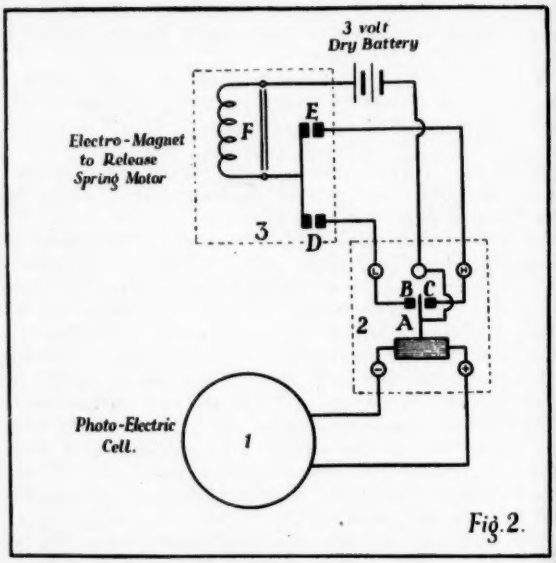

Fig. 2.

when O is depressed, contact E is made, and when raised, contact D is made. The lugs L and L^1 are bevelled in such a way that when the disc K rotates with the gas cock, the common member O is depressed by L^1 into contact with E and raised by L into contact with D. The disc K is coupled to the gas cock so that the common member O is raised into contact with D when the gas cock is "off," and is depressed into contact with E when the gas cock is "on." The object of this arrangement of contacts is to permit an electric impulse to pass through the coil of the magnet, thus setting the spring motor into motion, and then to interrupt the flow of current. Current is thereby economised, and it becomes possible to operate the device by a small dry cell. The function of the switches is made clear by considering

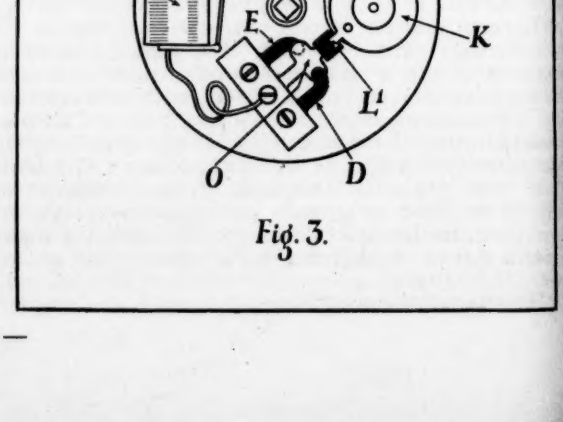

Fig. 3.

the sequence of operations of the complete apparatus.

Assume the natural light falling on the photoelectric cell is at the standard intensity. Then the current generated by the cell will deflect the conductor A (Fig. 2) of the relay into the neutral position; the gas lamps are "out" and contact D (Fig. 2) is "made." Now as the light diminishes to the lower limit, A approaches B, and eventually they touch, consequently a current flows along the path A, B, D, F. The electro-magnet is energised, and the spring motor is started. The control cock is thus turned to the "on" position, and simultaneously contact D is "broken" and E is "made," hence the battery circuit is broken, and current ceases to flow from the dry cell. The position now is: the gas burners are alight, contact D is broken, A and B are touching, and contact E is "made" ready for the next operation to extinguish the burners. As daylight improves the moving conductor A leaves contact B, and when the upper limit of daylight is reached A and C come into contact. A current now flows in the circuits A, C, E, F, operates the magnet, turns the gas cock into the "off" position, and contact E is "broken" at the same time contact D is made in readiness for the next operation.

DISCUSSION

DR. J. W. T. WALSH emphasised the number of applications of photo-electric cells which the papers described. It was clear that many more applications would be devised in the future. Referring to the use of these cells by the London Passenger Transport Board for causing the trains to switch on warning lights at the platforms where there was a rather large gap between platform and train, he suggested the Board might go a step farther and give an audible warning, "Mind the Gap," at the same time. Speaking again of other applications of the photo-cells, he said that at the present moment he was seeking something which would record supply voltage fluctuations to an accuracy, if possible, of one-tenth of one per cent. There was no moving pointer instrument which would do this, and he proposed to investigate the possibilities of photo-cells in this connection.

LIEUT.-COL. KENELM EDGCUMBE expressed the view that Mr. Walker had been a little pessimistic in his paper with regard to the rectifier cell. Reference had been made to an error of 20 per cent., owing to want of linearity, but there was no reason why there should be any error, because presumably the instrument would be calibrated or the relay adjusted to take care of any want of linearity. As regards the temperature error of 0.3 to 0.5 per cent. per degree C., the new B.S.I. specification for these cells provided for a maximum of 0.3 per cent., and it was quite easy to keep below that figure. Again, Mr. Walker spoke of considerable error when the angle of incidence of the light exceeded about 60 deg., but the new specification provided that it must not exceed 5 per cent. up to 65 deg., and for these reasons he felt the rectifier cell was in a much better position than Mr. Walker indicated. Speaking of the smoke-detecting apparatus mentioned by Mr. Walker, he asked how the windows were kept clean, as he would imagine they would get obscured by the smoke passing them.

Referring to Mr. Hall's paper, he asked what was the difference in the foot-candle illumination at which the arrangement he had demonstrated switched on and switched off. Also, could Mr. Hall say how nearly it repeated the reading for switching on and switching off?

In Mr. McDermott's paper there was a reference to the window frame being screwed up, but he could not quite see the connection between the window frames and the readings on the cell. He asked if Mr. McDermott used a light filter. His own experience was that daylight illumination varied according to the class of daylight—whether the sky was overcast or whether it was clear. He imagined Mr. McDermott used a filter of some sort, and, if so, could he give some particulars?

MR. V. H. GILBERT said that Mr. Walker was a little misleading when he said that in the case of the circuit shown using the selenium cell a delay of half a minute was of little consequence. Actually, in practice that did not occur, because the cell was following the change of daylight. With reference to the smoke-detecting apparatus and Mr. Walker's suggestion that a qualitative record which merely showed "smoke" or "no smoke" was preferable to the quantitative record which indicated degrees of smoke density, Mr. Gilbert said that his experience was contrary; considerable care had been taken in design of the particular circuit, and variations due to valve, lamp, and soot deposits on the windows were easily compensated and checked. The arrangement was such that very appreciable changes could occur and yet accurate smoke indications be recorded satisfactorily. Replying to the question by Lieut.-Col. Edgcumbe as to keeping the windows of smoke-recording apparatus clean, he said that if the flue gases were under a slight vacuum, the in-drawn air was sufficient, as a rule, to keep the windows clean. In the case of large power stations, it was usual to enclose the windows and to arrange an air draught inside the flue to blow on the windows and keep them clear in that way. Alternatively, it was possible to have water jets playing on the window, although this introduced certain difficulties which it was well to avoid, if possible.

Commenting on Mr. Hall's paper, he said his company had considered the control of gas lamps in the way demonstrated, and some years ago they had worked a similar sort of relay with the selenium cell to control outdoor gas street lamps very satisfactorily for more than twelve months. In endeavouring to control gas lamps in this way he had worked with a small high-tension battery of 60 or 70 volts, giving 9-12 months' service, instead of the 3-volt cell used

by Mr. Hall. Otherwise, there was not much difference in the apparatus. The idea was fundamentally practicable.

Communicated.—In regard to Mr. McDermott's paper, it would be interesting to know at what light intensity the various operators did, in fact, switch on their desk lights, and whether he considered their work or efficiency would be improved if the desk lighting was automatically controlled by a light-actuated unit from the daylight intensity, such as in street lighting, thus removing from the typists the onus of switching on and off as required.

Dr. S. English raised the question of nomenclature in regard to light-sensitive cells, and referred to the International Conference in Berlin and Karlsruhe last summer, when there was a discussion on that matter. There, it was suggested that so many names were being used for light-sensitive cells that some confusion arose, and it was urged on that occasion that the names by which these light-sensitive cells were known should bear some relation to the characteristics of the cells. In Mr. Walker's paper, for instance, the selenium cell was referred to when obviously the resistance type was meant. He suggested it would be better if the nomenclature recommended in Germany last year could be adopted.

As to the measurement of light by cells, he agreed with Mr. Walker as to the use of vacuum-emission cells when it was desired to measure light quite accurately. For some years he had been using a photometer in his laboratory with a vacuum cell and an electrometer for polar curve determinations, and this method had never given the slightest trouble. He still got curves which repeated perfectly, and all that was necessary was occasionally to renew a dry battery. With Lieut.-Col. Edgcumbe, he agreed that Mr. Walker had spoken in a negative kind of way not too favourably of the rectifier type cell, and especially with regard to the comment on the possible error of 20 per cent. in the response of the cell. It all depended on how the circuit was arranged and how the instrument was used. It would be fairer if it were made clear in a positive statement that the current could be made proportional (to the light received by the cell) if the apparatus was designed and used properly.

Speaking with regard to Mr. McDermott's paper, Dr. English asked for further information on one point. The tests with the typists would be extremely useful, and he would much rather have tests of that kind than certain other types of tests with which many of them were familiar. Could Mr. McDermott say whether the typists knew they were being watched by the light-sensitive cell, because the value of the results would be influenced by that fact? For example, if they knew they were being watched (and records kept) they might not put on the artificial lighting when it was really necessary, in order that they might not be thought extravagant. Finally, could Mr. McDermott say what were the foot-candle values at which the lights were ordinarily switched on?

Mr. P. B. Renshaw said that his company had put in an installation of light cells for controlling traffic signals in Surrey by pedestrians, and one of the curious things noticed was that the colour of the vehicles affected the detectors in different ways. For instance, a red bus was noticeable in its effect on the cell, and he believed he was right in saying that this arose because the cells were particularly sensitive to the red end of the spectrum and the sky light reflected on the bus tended to make the relay drop again. Mr. Walker had mentioned that a lot of light was lost by using infra-red, and that was quite true, but a point in favour of infra-red was that it helped to stop extraneous light having an effect upon the cells. That had been a big trouble in the open air, where steps had had to be taken to stop interference from the sun. This trouble was not encountered in indoor applications such as factories.

He gathered from the paper that the method of counting, making use of the closing of the charging circuit of a condenser at each impulse—the condenser discharging through a neon lamp and auxiliary relay, which actuated the counter at each discharge—was not altogether reliable. That was how he read the paper, but he had done a certain amount of work in that connection and had found the number of impulses of the neon lamp was reasonably constant.

The problem of the window in the smoke-detecting device becoming obscured was really a question of the margin of safety provided, and he imagined that a certain amount of soiling of the window would be provided for in the design before defective working was reached.

He had been surprised to see in Mr. McDermott's paper the statement that the glow of the cell did no harm, because the manufacturers of the cells had strongly warned users against allowing the cells to glow for fear they blew up or did something of the sort. He should hesitate to believe that the cells supplied to the National Physical Laboratory were superior to those supplied to ordinary users!

Finally, he associated himself with previous speakers in congratulating Mr. Hall on the bravery he had shown in associating even three volts of electricity with gas, for he himself had had bitter experience trying to fit electric traffic signals on to gas standards.

Mr. J. S. Preston asked Mr. Walker if there had been any experience of amplification methods using rectifier cells as a voltage generating device. He believed some d.c. amplifiers had been designed for this purpose, but would like to know if they had been successful. Mr. Walker had mentioned the use of emission cells as a comparator in which two sources of light illuminated the cell alternately. Some further information in that connection would be interesting, especially with regard to any difficulty of changing over from one source to the other smoothly without the introduction of extraneous

harmonics. The question of the stability of rectifier cells, both for relay operation and direct measurement, might also be dealt with in greater detail.

Referring to the tests with the typists, Mr. Preston said it occurred to him that the value of the daylight illumination at which the artificial illumination was switched on might be dependent on the amount of artificial lighting made available by the desk lights. For instance, different results might be obtained in a different office where the desk lights were of an appreciably higher wattage. He suggested, therefore, that to complete any statement of results, it was desirable also to indicate the order of the artificial illumination available on each desk.

Finally, Mr. Preston suggested that one other application of the light cell might be to make it possible to blow the other man's horn when approaching a blind corner.

MR. C. H. DOBELL said that whilst his colleague Mr. Gilbert had dealt with some of the technical aspects, he wished to impress upon the members the enormous use that was being made at the present time of light-actuated switches. Many miles of street lighting were controlled in this way in this country, as well as a large number of illuminated traffic signs. In addition, most of the large power stations here were using smoke indicators actuated in this manner, whilst another large use was counting. He mentioned this, he said, to dispel any idea that this matter was in the experimental stage. It was a method of control which was not only in existence, but was making tremendous headway.

MR. P. J. WALDRAM remarked that the reference by Lieut.-Col. Edgcumbe to the " psychological " moment of switching on artificial lighting was possibly more important than the speaker intended it to be. For many years the measurement of adequacy in daylight had been considered to be a purely photometric problem. Actually, except for the lower limit of one foot-candle, the eye used and judged daylight according to factors which were partly physiological and mainly psychological.

So largely was it a matter of contrast rather than amount that he had often been tempted to question whether there were any practical value in the photometric values of daylight variations laboriously collated at Teddington. In this he had been wrong. The recently published " Technical Paper No. 17," giving the analysed results of daily records of daylight variations over a period of ten years, was a valuable document, not only because it was a unique record of which British research might well be proud, but also by reason of the fact that it killed certain exaggerated, even fantastic, theories which had been put forward with the object—not perhaps entirely disinterested—of justifying excessive obstructions.

When some thirty years ago it was ascertained that the "grumble point " of ordinary people as to daylight illumination remained fairly constant under large variations of weather, could be measured as a certain ratio of inside to outside light, and could only be so measured, difficulty was experienced in inducing anyone to believe that the eye could be affected by a ratio, or by anything less physical than measurable insufficiency. The idea of the " grumble line " in a room remaining constant from dawn to dusk and in winter and summer also seemed unreasonably miraculous. In consequence, attention was focused on the fact that there was also a lower limit of inadequacy due to measurable inadequacy, irrespective of position in a room represented by the " grumble ratio " at such times as the sky had such a brightness that 500 foot-candles was to be obtained from a complete unobstructed hemisphere. This, when coupled with the fact that the 500 foot-candle sky obtained on wet or dull days from dawn to dusk, irrespective of the height of the sun, and therefore of latitude, and the further obvious fact that people required to work indoors in wet weather no less than in fine, served to establish the " grumble point "—first legally and later internationally. Those who wished to avoid it were compelled to make inaccurate deductions from selected records of the partial publication of the Teddington records. We are now in possession of a categorical statement in " Technical Paper No. 17 " that records over ten years show that 500 foot-candles is a fair figure for dull days, as the well-known " Technical Paper No. 7 " had prophesied would be found to be the case.

With regard to the typists' test, it was to be hoped that due cognisance would be taken of the fact that obstructed rooms could have " grumble areas " inside which light was always insufficient whether it were 1 or 10 foot candles. According to his recollection the " pooled " typists in the Whitehall Government offices worked in a basement partially top lit where the " grumble area " was so pronounced as to require artificial light at all times. A more important point was that there was a considerable difference between the sense of inadequacy experienced by the human eye during the slowly waning light of a fine afternoon or evening, and the pronounced changes during a windy March day with rapid alternations of sunshine, clear sky, and dark storm clouds. He would expect to find typists continuing to work comfortably at, say 1 foot candle under the former conditions, and yet switching on when the light dropped suddenly to, say, 2 or 3 foot candles under the latter.

It was in this connection that the use of the word " psychological " by Lt.-Col. Edgcumbe had such considerable significance, and he hoped that the records of these tests would be carefully examined and considered by psychological experts and their value thereby considerably enhanced.

Referring to smoke recorders, Mr. Waldram enquired whether in the case of smoke prosecutions the fact was taken into account that the apparent density of so-called black smoke depended a great deal on the brilliance of the sky behind it. It seemed to him that the only possible fair recorder of smoke density from the ground was one which took simultaneous readings of the brightness of the sky in the vicinity of the smoke and the extent to which that brightness was diminished by the smoke.

MR. F. C. SMITH, commenting upon the President's remark at the opening as to the willingness of the

gas engineer to use electricity, said that this was perfectly true. The gas industry was always willing to use electricity when this form of energy had an outstanding advantage for the work in question. At the same time, he observed that electrical engineers were using gas—and using it very plentifully—when gas was the obvious form in which to supply energy.

Expressing his agreement with what Col. Edgcumbe and Dr. English had said with regard to the comments in the paper on the rectifier cell, Mr. Smith said he had had occasion recently to use that type of cell, but before doing so he made very careful calibration of the proportionality and also went very carefully into the temperature effects. As a result of that experience he felt Mr. Walker had been a little unjust to that type of cell. Anyone who had used photo electric cells appreciated that they required a certain amount of skilful handling and the danger was that these light cells might be put into the hands of people who knew nothing about photometry or photo electric cells and who simply put them in and hoped for the best. At the same time, with reasonable precautions the rectifier cell gave very good results.

There were two difficulties in the use of light cells for controlling gas street lamps. The first was that dry cells had to be relied upon, and, quite frankly, that was the weakest point in the electrical armoury. This was the reason why he did not like to rely upon dry cells in places where they would be subjected to big changes in temperature. Dry cells, when used under these conditions, resulted in high maintenance charges. The second difficulty arising from the operation of street lamps by photo electric cells was one of accountancy. This difficulty, however, was common to both gas and electricity. In congratulating Mr. Hall upon his application of the light cell to the control of gas lighting in schools, Mr. Smith pointed out that the cock used in this case was of excellent design and, in consequence, required very little power to operate.

A difficulty which was not realised as much as it should be in connection with smoke detectors was keeping the windows clear from tarry matter. He felt that the playing of an air blast on to these windows would not overcome this difficulty.

Finally, Mr. Smith called attention to the fact that street lamps can be effectively operated by pressure controllers. It was interesting to note that this system had been in use in Berlin for a number of years.

Mr. G. H. Wilson, referring to the value of illumination at which street lighting units are set to operate, said he had been interested in devising a lighting-up table, and a short series of experiments had indicated that about one foot-candle illumination on the horizontal surface was the level at which a number of people would like the street lighting to come on. He asked whether the controllers mentioned by Mr. Walker were set to operate at a definite value, and whether it was possible to have a recorder which would indicate the time at which the daylight illumination on a horizontal surface fell to one foot-candle.

Mr. L. H. McDermott, dealing with the discussion on his paper, said in reply to Colonel Edgcumbe that it was necessary to screw up the window as the window frame was found to obscure the photo-cell when opened for the purpose of ventilating the office. With regard to the question of using a filter, this was not thought desirable, partly because of the fact that the cell used was very similar to the eye as regards spectral sensitivity, and partly because of the loss of sensitivity if one were used. Also the spread of the readings was expected to be sufficiently large for the mean to be almost unaffected by some of the readings being, say, 20 per cent. in error; these errors would arise on clear days, as all the calibrations were effected on cloudy days.

In reply to Mr. Gilbert and several subsequent speakers, the author very much regretted that as yet it was not possible to state the value of the illumination at which the typists switched on. To Mr. Gilbert's suggestion of having automatically-controlled office lighting, there are several serious objections that would tend to make it difficult to apply in practice, although seemingly desirable in theory. In any office such as that used for this investigation, all the typists were found to work at different daylight factors, and hence it would be necessary to have a separate relay for each typist and each relay would have to operate at a different current. If, however, all the desk lights were switched on at the same time as that over the desk having the lowest daylight factor, this would be unnecessarily wasteful. Further, typists are often called upon to copy from small or indistinct print, and this might become a matter of some difficulty were the control of their individual desk lights taken from them.

Replying to Dr. English the author said that it was not found possible to keep the typists in ignorance of the fact that a test was in progress, although they were quite unaware of the nature of the test.

To Mr. Renshaw the author replied that as the cathode of the cell was of bulk potassium, a glow discharge caused little or no damage and the sensitivity was almost unaffected.

The author thanked Mr. Preston for his suggestion regarding the value of the artificial illumination made available by the desk lights, and agreed that it would be desirable to possess a knowledge of this figure.

The author also expressed his thanks to Mr. Waldram for his remarks and assured him that the suggestions made would be carefully considered. "Technical Paper No. 17," mentioned by Mr. Waldram, was compiled from visual measurements taken at set times and it was these that had been used in the calibrations of the photo-electric records.

Mr. R. C. Walker, in replying to the discussion on his paper, said that he had possibly overstressed the error in proportionality of the rectifier type of cell; but in respect of temperature coefficient, although he was interested in what had been said concerning the British Standards Specification, he had known cells of this kind with considerably greater temperature error than even he had mentioned—as much as 1 to 1.5 per cent per degree C., which over the range

of extreme summer and winter temperatures would result in more than the 20 per cent. error mentioned in respect of linearity. His experience had been that most of the devices for keeping the windows of smoke detecting apparatus clean were more or less unsatisfactory, and if it were possible to get rid of them it was preferable to do so. To have merely a small hole without any window was the best arrangement, providing the difference between external and internal pressure was not too great.

In reply to Mr. Gilbert, he agreed that the Selenium Cell Circuit shown followed the light changes when these changes were slow. Under any other conditions the delay was present as it was in all circuits involving the charging of a condenser. He had not had the same experience as Mr. Gilbert in measuring circuits, and found that the substitution of one valve for another affected the conditions of operation much less in a trigger circuit than in a measuring circuit.

He agreed with Dr. English on the question of nomenclature, and enquired whether the recommendations suggested had been internationally agreed.

As to pedestrian crossings controlled by light cells, he failed to see how this arrangement could be satisfactory in all cases, particularly when installed at the edge of the pavement, since the pedestrian had to step on to the road before he could set the signals in his favour. There were many ways of removing the disturbing effect of extraneous illumination, such as the use of bridge circuits or baffled tubes over the photo-cell, though the former involved extra complication. With regard to the condenser charging circuit for counting, the accuracy depended on the constancy of the charge, which in turn depended on surface leakage. If the charged condenser was left for any length of time there was bound to be some loss by leakage. He had never been able to get such circuits to work consistently if the time during which the charge was held exceeded three or four minutes. He would like to hear the experiences of others in this connection.

In reply to Mr. Preston he said that it was possible to get some amplification from the rectifier cell when used as a voltage generating device, but the arrangement was very inefficient compared with the alkali metal cell, by reason of the low internal resistance of the rectifier type. The question of illuminating a photo-cell from two sources alternately had been dealt with in the paper, but the slide which illustrated the principle had been cut out owing to shortness of time available. Such an arrangement had been used in America for examination of the selective reflecting properties of surfaces. Light from a common source was reflected from two surfaces and directed into a rotating shutter which had alternate quadrants removed, and the remaining quadrants silvered. As the shutter rotated, the photo-cell received light from one surface reflected from the shutter quadrant and direct light from the other surface. The out-of-balance current in the photo-cell circuit, after amplification, was made to actuate a shutter to secure equality and at the same time give an indication of difference of reflective properties of the surfaces.

So far as he was aware the question of wave form and harmonics had not been considered in such apparatus. It was always possible to secure a photo-electric current of any desired wave form by suitable design of the shutters through which the intermittent light reached the cathode.

The final suggestion of Mr. Preston, that of being able to blow the other man's horn coming round a blind corner, had not yet been attempted, but it had been suggested on several occasions that light cells should be used to dim the other man's headlights, unfortunately by people who overlooked the fact that this would always leave the man with the strongest headlights with the right of way.

With regard to the control of gas furnaces, this had not been mentioned in the paper, but had been applied in several instances with oil fuel supply as well, the fuel being cut off automatically as soon as the flame was accidentally extinguished, so that the possibility of an explosion through the accumulation of combustible material in the fire box was avoided.

Finally, he suggested that Mr. Wilson's question could be best answered by Mr. Gilbert, whose company manufactured the apparatus referred to.

MR. W. H. B. HALL, replying to the comments on his paper, said that the instrument used in the school mentioned in his paper was actually set so that the lights would come on when daylight fell to 5 foot-candles on the darkest working place. When daylight at this point rose to 7 foot-candles the lights were extinguished. The accuracy with which the apparatus worked was about half a foot-candle on the working bench. He had purposely refrained from saying anything about the position of the photo-electric cell because that was a matter of trial to find a position for the cell where the light falling on it would bear a definite relation to the light falling on the darkest working bench. As to the gas cock being of special design, the aim throughout had been to use components which were in common use and had proved to be satisfactory.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

Printed by the ARGUS PRESS, LTD., Temple Avenue and Tudor St., London, E.C.4, England.